DOCTOR OF PHILOSOPHY

Investigating the potential of remote sensing for long-term limnological analysis at pan-continental scales

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Abbreviations

AISA	Airborne Imaging Spectrometer for Applications
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATM	Airborne Thematic Mapper
AVHRR	Advanced Very High Resolution Radiometer
CDOM	Coloured dissolved organic matter
CZCS	Coastal Zone Colour Scanner
df	Degrees of freedom
DN	Digital number
DSRS	Dundee Satellite Receiving Station
ETM+	Enhanced Thematic Mapper
IFOV	Instantaneous field of view
LST	Lake surface temperature
L_{toa}	At-satellite (or top-of-atmosphere) radiance
MCSST	Multi-channel sea surface temperature algorithm
MERIS	Medium Resolution Imaging Spectrometer
MSS	Multispectral Scanner
MODIS	Moderate resolution Imaging Spectroradiometer
n	Sample size
NEODAAS	NERC Earth Observation Data Acquisition and Analysis Service
NERC	Natural Environment Research Council
nIR	Near Infrared
NLSST	Non-linear sea surface temperature algorithm
nL_w	Normalized water-leaving radiance
NOAA	National Oceanic and Atmospheric Administration
OC3	Ocean Colour 3 algorithm
PML	Plymouth Marine Laboratory
ρ	Spearman's rho correlation coefficient
r	Pearson's correlation coefficient
R^2	Coefficient of determination
RMSE	Root mean square error
R_{rs}	Water-leaving remote sensing reflectance

R_{toa}	At-satellite (or top-of-atmosphere) reflectance
SDD	Secchi disk depth
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SST	Sea surface temperature
TIR	Thermal Infrared
TM	Thematic Mapper
TSM	Total suspended matter
WFD	Water Framework Directive

Abstract

Lakes are key indicators of environmental change and major repositories of biodiversity and ecosystem services. However, studies of lake response to drivers of change at a pan-European scale are exceptionally rare. The need for such studies has been given renewed impetus by concerns over climate change and because of international policy-related schemes, such as the EU Water Framework Directive that has made it legal requirement to repeatedly assess and monitor the ecological status of European lakes toward their effective management and sustainable use. This has introduced the need for methods that can be widely applied across large spatial and temporal scales and produce comparable results. Remote sensing is a promising method for providing such information, but the spatial transferability and temporal repeatability of methods and relationships observed remains untested.

In this project, an extensive dataset of field measurements was compiled covering temperature, chlorophyll *a* and Secchi disk depth in 23 European lakes spanning the last 30 years. The characteristics of these lake systems were explored and similarities in their ecological behavior identified, thus providing the basis for their grouping. Then the potential of remote sensing for estimating and monitoring lake water quality at wide spatial and temporal scales was assessed and thus the long remote sensing archive at the NEODAAS DSRS was fundamental for the purposes of this project. Using NOAA AVHRR, Terra/Aqua MODIS and field data from lakes that represented three main lake groups, the spatial and temporal reliability of 26 existing water quality estimation algorithms was assessed. Following this, the best performing algorithms were applied to

all study sites and the effect of scale and spatial resolution upon reliable estimation of key water quality parameters was evaluated.

It was demonstrated that the NOAA AVHRR and Terra/Aqua MODIS were both capable of producing highly accurate ($R^2 > 0.9$) lake surface temperature estimates in lakes with variable characteristics and a variety of thermal spatial features, and long-term patterns within the study sites could be studied with NOAA AVHRR data despite the relatively coarse spatial resolution of the sensor. Restricting factors to the latter were the size and shape of lakes and the frequency of cloud cover. By contrast, the development of a universal Terra/Aqua MODIS algorithm for the estimation of chlorophyll *a* and Secchi disk depth in variable lakes was more challenging due to the optical complexity of Case II waters. Terra/Aqua MODIS data showed a potential, but the use of a different technique (e.g. multivariate regression or neural networks) and/or a different sensor (e.g. Envisat MERIS) could potentially improve the predictive accuracy of the algorithms.